A Proposed Synopsis on the topic

“Impact of AGN Feedback on the enrichment of intra-cluster medium”

A synopsis submitted to

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Introduction :

Clusters of galaxies are the most massive gravitationally bound objects in the Universe. They include hundreds of galaxies within a radius of 1–2 Mpc (e.g., Abell, 1958). The cluster mass is comprised of different component, ~5-8% of luminous matter in the form of stars, ~12-15% in the form of X-ray luminous diffuse hot gas that fills the space between galaxies known as Intra-cluster medium (ICM), while the remainder ~80% of the mass exists in the dark matter form that cannot be detected. However, effect of the existence of the last component can be inferred through its gravitational effects. In optical window the galaxy cluster were observed as isolated galaxies, while in X-ray window the galaxy clusters appeared as the single, extended entities covering regions much wider than 1 Mpc and X-rays luminosities ranging between 10^{43} - 10^{44} erg s^{-1}. Many of the galaxy clusters host a central giant elliptical galaxy that is considerably brighter and more massive than any other member in the cluster (Exploring the X-ray Universe book, Frederick et.al 2nd edition). e.g. Virgo and Perseus clusters consists M87 and NGC 1275 as central brightest galaxies. The ICM that emits X-ray has temperature in the order of 10^{7}- 10^{8} K and is comprised of fully ionized hydrogen and helium plus traces of highly ionized heavier elements at about a third of their solar abundances (Maxim et.al , 2007). The X-ray emission from medium is mostly originated via thermal Bremsstrahlung with efficiently.

Cooling flows in Galaxy clusters:

1) Early study of X-ray emission from ICM in majority of galaxy clusters exhibited sharply peaked X-ray surface brightness profiles pointing towards the very high density of the X-ray emitting gas at the centre.

2) Temperature profiles computed showed decline towards the core of the cluster.

Both these results imply that plasma in the cores of these clusters is cooling rapidly than Hubble time through the radiative emission process.

Cooling flow (CF) model describes the mechanism and nature of cooling procedure of hot ICM. “Gas in the very dense central regions of massive clusters radiate away its energy and cools down rapidly to the molecular phase in absence of any heating process. The gas after losing its energy gets compressed in the central region so as to compensate weight of the overlying gas layers. As a result, hot gas in outer regions of the ICM rushes to replace the compressed gas leading to

catastrophe of the flow of the cooling gas towards the central region (Fabian , 1994).” This flow of cool gas in the central region is commonly referred to as the Cooling flow. The standard cooling flow model does not assume heating sources to operate at the central region of the clusters so as to heat the ICM to such a high temperature. However, observational evidences suggest that there must be some mechanism that injects extra energy into the ICM to prevent the cooling of ICM.

Following are proposed heating sources: 1) energy injection through the supernova explosions.

2) conduction from the surrounding ICM.

3) heating by dynamical friction, dark matter interactions, cosmic rays, merger shocks.

4) gas sloshing in the cluster core.

5) mechanical and radiative feedback from AGN (Active Galactic Nuclei).

6) starburts.

Among above all proposed heating sources the AGN feedback is most efficient and evidenced sources which can heats the ICM up to 10^{61} ergs energy.

Systematic studies of the cool core clusters in last two decades have demonstrated that AGN are powerful enough to generate sufficient amount of energy to quench the cooling flow in the cores of the clusters. However, the exact mode in which the energy transferred to ICM is not clear (Fabian, 2012). The proposed models that support the AGN heating of the core of the galaxy clusters must produce some impact on the surroundings. These impacts could be evidenced in the form of

1) inflating buoyant bubbles

2) shocks and sound waves

3) turbulence

4) cosmic rays.

Abstract of Study :

Present study aims to investigate the emission properties of AGN and its impact on the evolution of the host galaxies, therefore, invites multiwavelength observations of a critically selected targets. Most galaxies pass through one or more active phases at some point during their evolution. If so, then comparing the luminosity evolution of AGN host galaxies to that of normal galaxies allow us to study the link between AGN activity and galaxy evolution. If galaxy interactions are an important trigger of AGN activity then there is a link between AGN activity and the assembly of elliptical galaxies, which should be reflected in the luminosity evolution of AGN host galaxies .This study

will analyze high resolution data in optical broad bands as well as narrow bands, UV, X-rays and radio frequencies acquired/available in the archives of various observatories. We shall also submit our observing proposals to ASTROSAT, DOT, and GMRT on selected targets. In this study we propose to study the AGN feedback to understand the processes that are operative during galaxy evolution as a whole.

Review of Literature and Development in the subject :

Active Galactic Nuclei (AGN) are energetic astrophysical sources powered by accretion onto super massive black holes in galaxies, and present unique observational signatures that cover the full electromagnetic spectrum over more than twenty orders of magnitude in frequency. Active galactic nuclei (AGNs) are most fascinating objects of present time and availability of the state of art space borne observing facilities across the electromagnetic spectrum have rejuvenated our interest in investigating their properties. AGN releases a tremendous amount of energy in the form of radiation, winds or jets, which collectively create great impact on surrounding medium. As a result of release of these properties processes, known as the AGN feedback, present the gas accretion on the central black hole and redistribute it by driving massive outflows suppressing the star formation and hence play a key role in the evolution of the host galaxies. Radiation, winds, jets from the active nucleus of a massive galaxy can interact with its interstellar medium, and this can lead to ejection or heating of the gas. This terminates star formation in the galaxy and stifles accretion onto the black hole. Such active galactic nuclei (AGN) feedback can account for the observed proportionality between the central black hole and the host galaxy mass. It has been realized over the past decade that the black hole at the centre of a galaxy bulge is no mere ornament but may play a major role in determining the final stellar mass of the bulge. The process by which this occurs is known as AGN (active galactic nuclei) feedback, and it takes place through an interaction between the energy and radiation generated by accretion onto the massive black hole (the active nucleus) and the gas in the host galaxy. The possibility arises where the intense flux of photons and particles produced by the active nucleus sweeps the galaxy bulge clean of interstellar gas, terminates star formation, and, through lack of fuel for accretion, terminates the active galactic nucleus. Therefore to understand scenario of evolution of galaxies and impact of AGN feedback on it and also to understand the physical mechanisms that trigger evidenced activities of AGN, a systematic study of AGN’s and properties of their host galaxies is called for.

In the review article “Cooling flows in Clusters of Galaxies ” Fabian 1994 has presented an excellent analysis on galaxy clusters and cooling flows comparing information acquired using all the observational bands. This study mainly focus on X-ray imaging evidences and X-ray spectral

evidences with theoretical issues in cooling flows. General properties of the ICM have been reviewed by Sarazin (1986, 1988, 1992), Mushotzky (2004), Arnaud (2005) and Fabian (1988b). Spectroscopic properties of cluster of galaxies in X-ray band studied and reviewed very well by Mushotzky (1984). Comprehensive review of the X-ray images of clusters done by Forman and Jones (1982). McNamara and Nulsen (2007) have an excellent review of the current evidence in support of AGN as the heating mechanisms in cool core clusters.

Scientific Objectives of study :

Main objectives of the proposed study are:

1. To understand the interplay between the super massive black hole due to accretion and its effect on the evolution of host galaxy.
2. To investigate the connection and physical mechanism between optical and radio emission from AGNs.
3. To study the effect of AGN-feedback on the ICM enrichment and star formation in the host galaxy.

Methodology :

As scientific goal of this study is to investigate the impact of AGN feedback in the environment of the central dominant galaxies in the core of groups and clusters, therefore, proposes to utilize deep, high-resolution X-ray observations on the critically selected targets available in the archive of the Chandra X-ray Observatory. To delineate its association with the radio jets, this work also proposes to utilize multi-frequency radio data acquired using Giant Meter wave Radio Telescope (GMRT), Very Large Array (VLA), NRAO Science Data centers.

For the study of X-ray emission properties of central dominant galaxies, we would like to use data available in the archives of space observatories like Chandra, XMM-Newton, SUZAKU, etc. In addition to this archived data, we plan to get fresh data from the Indian space machine ASTROSAT by submitting our own proposals. We have made a survey on the availability of data in the archives of these observatories and have confirmed the availability of data on the target galaxies. This data will be used for studying morphology and spectral properties of X-ray cavities in the cooling flow galaxies. In addition to this, with a view to study association of these cavities with their optical and radio counterparts, we would like to observe some of these objects in optical and near-IR bands using the National facilities at Devasthal Observatory, Himalaya Chandra Telescope (HCT), etc. We

will also submit proposals to 8-meter South African Large Telescope (SALT), South Africa. India is one of the partners of SALT project in which 10% of the observing time is reserved for Indian proposals. Radio observations will be taken with the help of Giant Meter-wave Radio Telescope (GMRT), TIFR-Mumbai.

Data Analysis:

X-ray data acquired using Chandra and XMM-Newton space telescopes on the target galaxies will be reduced and analyzed in a uniform, self-consistent manner using the scripted analysis pipeline employing the CIAO (Chandra Interactive Analysis of Observations) and in conjunction with Chandra calibration database (CALDB) provided by Chandra X-ray Centre (CXC). X-ray data acquired from XMM-Newton will be analyzed in a similar way using SAS (Science Analysis System), respectively. For spectral analysis of the X-ray data XSPEC software package will be used. The original Chandra data files will be reprocessed to update the instrumental gain and astrometry solution of the Chandra Calibration Database (CALDB). Telemetered raw data splits into FITS file format for each observation know as level 0. Next level applies the instrumental and time correction factors such as the aspect solutions and positions of bad pixels etc to level 0, the resultant events are known as level 1. In level 2 stage we will apply the latest calibration to level 1 file to get latest gain correction, the best filtering and to match to the background files, we will generate the level 2 event file by using *chandra_repro* scripts. Next step of the data preparation is removing the background flaring by using *lc_sigma_clip*. Short periods of significantly-enhanced background count rate, known as "flares", will be removed using the iterative 3-sigma clipping technique (Strickland 2002). This results in deriving the net “good" exposure times of the observations and will be used for the further analysis of the Chandra observations.

From this pre-processing, we would like to derive three different kind of information: diffuse X-ray emission maps, spatial distribution of X-ray photons (radial intensity profile) and spectral energy distribution of photons.

In practice, fully-automated point source detection is not perfect, because in some cases the right features in the diffuse X-ray emission will be identified as point sources. While it is also possible that, low S/N features that most probably are genuine point sources will be missed by the source detection algorithm. Therefore, it is required that one must assess each feature carefully and remove those that appear to be point-like based on our personal scientific judgment.

For generating diffuse X-ray emission maps we would like to use level-2 event files of the target galaxies. These images will be first filtered to extract all the incident photons in different energy bands, soft (0.3 - 1 keV), medium (1- 2 keV) and hard (2- 8 keV) bands, using *dmcopy* thread available within CIAO v4.14. Any point sources present in the images will be physically identified

and removed by using the task *wavdetect*. These holes, created due to removal of point sources, will be filled in by extrapolating the background value using the task *dmfilth*. Finally, a smooth, X-ray emission map representing the diffuse hot gas distributed within the target galaxy will be generated using the task *csmooth*. Radial Profile of Diffuse X-ray Emission and Point Sources detection is one of the important tasks of the analysis part.

Task *wavdetect* will be employed for the detection of the individual point sources present in the target galaxy. All the point sources lying within the optical extent of the host galaxy, defined by D25 ellipse, will be identified and catalogued properly by deriving their luminosity function, hardness ratio. For each galaxy, spectra of all the detected sources within D25 of the target galaxies will be extracted and integrated into a single spectrum using the CIAO routine *acisspec*. This routine calculates a weighted redistribution matrix file (RMF) and ancillary response file (ARF) appropriate for extended sources spread over the ACIS detector. Finally, using package *Sherpa* or XSPEC these extracted spectra of hot gas will be fitted. Several models are available in the library of *Sherpa*, and XSPEC however, for this class of targets MEKAL (plasma code); Bremsstrahlung or power law model in conjunction with the XSWABS (photoelectric absorption model) will be appropriate (Irwin et al. 2003).

The cleaned image will be further used to obtain the 2D smooth X-ray emission distribution from the cluster environment which will be treated with the 2-D beta model. We will also generate its unsharp mask image and surface brightness profile to highlight the spatial hidden features like cavities, shocks, cold fonts etc.

In order to obtain the spatial distribution of thermodynamical parameters like the temperature, abundance, hydrogen column density, pressure, electron density, entropy etc. We will performed the spectral analysis of the X-ray spectra. There are two type of spectroscopy analysis

1) Projected analysis – spectral analysis of the X-ray emission in a radial manner enabling us to derive the profiles of the temperature, metal abundance, density, pressure and entropy of the hot gas. *Specextract* scripts apply to event file to generated the spectral products a) spectrum, b) the Ancillary File (ARF) and c) Redistribution Matrix File (RMF) . Extracted spectra then will be fitted with models like (WABS, APEC etc.) in *sherpa* software tool.

2) Deprojection analysis - is useful to overcome the projection effect along the line of sight of ICM. Deprojected spectroscopy analysis will be carried out by using the *deproject* scripts.

The data from other observatories will also be processed following similar tools available for respective missions like XMM-Newton data, which will be processed using *SAS* while Radio data acquired using the GMRT observatory will be processed by *CASA*. All the necessary facilities for the analysis of multi-wavelength data are available at the School of Physical Sciences, S.R.T.M. University, Nanded.

Importance of Study :

The study of AGN itself is a discovery. All AGNs emit their energy in wide band of spectra. Modern instruments are capable enough to gather the useful information from great variety of objects and out to extremely high red shifts. For most of the past five decades the communities that studied galaxies and AGNs remained largely disconnected. AGNs were studied primarily as laboratories to probe exotic high-energy processes (Heckman et.al, 2014). AGNs also play an vital role in the evolution of galaxy clusters. The processes involved in the AGN feedback are not still understood well except the energetic aspects of the AGN. AGN feedback may partly account for several major outstanding questions in modern astrophysics, therefore, is an attractive problem for investigation. In this study we will discuss about primary observational evidences of AGN feedback with spectacular imaging and spectral features like cavities, shock fronts, and filaments embedded in hot atmospheres.

National and International status :

Active galactic nuclei feedback is being studied at global level due to the reason that its thorough understanding can answer some major outstanding questions in Astrophysics. There are several groups that are working in the field. However, the study by Prof. Andrew C. Fabian from University of Cambridge for the first time highlighted the AGN feedback problem in galaxy clusters and explored it through different observational windows. He for the first time published the best observational evidences on AGN feedback through kinetic and radiative mode. Prof. Brian R. McNamara from University of Waterloo, Canada studied the high resolution X-ray spectroscopic properties of the hot ICM in galaxy clusters. Prof. Myrian Gitti, Univeristy of Bologna , Italy studied the complex dynamical evolution of the intra-cluster medium (ICM) regulated by radiative cooling , evolution of galaxies, the history of star formation and formation of large scale structures.

At national level Prof. Dharam Veer Lal , Prof. C.H. Ishwar Chandra and Dr. Preeti Kharb from NCRA-TIFR , Pune. Prof. Somak Raychaudhury from Inter-University Center for Astronomy and Astrophysics (IUCAA) are also working on a similar problem. Prof. Joydeep Bagchi from Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune has been working on a similar topic by involving radio and X-ray observations of cluster galaxies.

Proposed Work Plan/ Formulation and Structure of study

YEAR 1: During the first year, as per the requirement of the UGC, New Delhi, I'll complete the pre Ph D Course Work and appear for the examination. Simultaneously, I will carry our literature survey on the topic of my research and also will learn the process of acquiring multi-wavelength

data on the targets of our study.

YEAR 2: In the second year of work, I'll learn the techniques of data processing using various astronomical software, like, CIAO, SAS, IRAF, AIPS, XSPEC, etc. I'll also submit observing proposals to various National and International observatories and will try to get high signal/noise ratio data on the targets of interest. Systematic analysis of the acquired data will performed in the following year.

YEAR 3: Results derived from this study will be presented in scientific meetings and / or research journals for publications.

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Prof. M. K. Patil — Research Guide

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